



(11)

EP 0 738 034 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
16.10.1996 Bulletin 1996/42

(51) Int Cl.6: **H02K 3/18, H02K 19/10**

(21) Application number: 96302409.6

(22) Date of filing: 03.04.1996

(84) Designated Contracting States:
DE ES FR GB IT NL SE

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(30) Priority: 10.04.1995 GB 9507391

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(54) Method and apparatus for reducing winding failures in switched reluctance machines

(57) A method and apparatus for reducing winding failures in reluctance machines wherein winding coils for the switched reluctance motor are formed and positioned such that the turn-to-ground capacitance of the portion of the winding coil coupled to an electronic motor controller is reduced. Alternate embodiments are disclosed wherein additional insulation, and capacitive voltage distributors are provided to enable a switched reluctance motor to better handle the voltage stresses produced when high frequency or high dV/dt voltage pulses are provided to the motor.

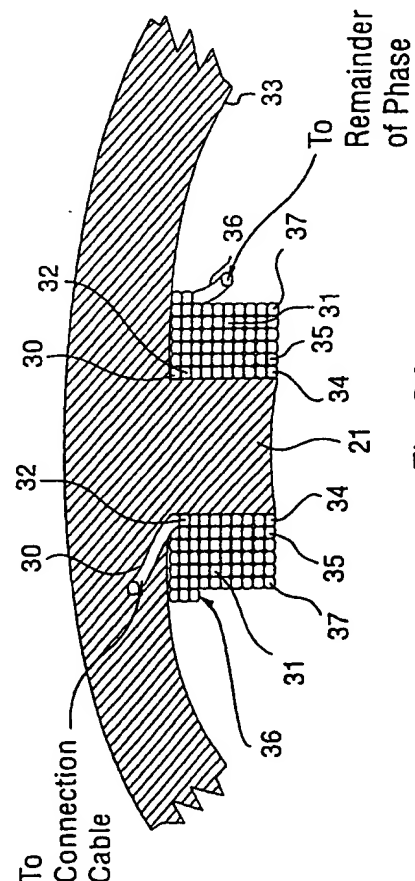


Fig 3A

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Description

The present invention relates to methods and structures for reducing winding failures in electric drive systems and, in particular, in switched reluctance machines.

Adjustable speed motor systems typically involve the use of specially designed electronic motor controllers coupled to the phase windings of a multi-phase motor via connection cables. An exemplary arrangement is illustrated in Figure 1 where a three-phase motor 10 is coupled to an electronic controller 12 by three connection cables 14, 16 and 18. In operation, cables 14, 16 and 18 act as transmission lines for signals which may take the form of voltage waveforms, provided by the electronic controller 12 to the motor 10.

In many systems, the electronic controller 12 controls the speed or torque of the motor 10 through the application of high frequency voltage pulses to the motor via the connection cables 14, 16 and 18. The frequencies of these applied pulses can be quite high and are often in the kilohertz range. Pulse frequencies of the order of 20kHz are particularly common, as the operation of switching devices at such speeds does not produce audible noise. The high frequency pulses often take the form of voltage waveforms having steep edges where the voltages change abruptly from a relatively low voltage level to a relatively high voltage level (or vice versa) over a short period of time. The rate of change of the applied voltage over time is mathematically represented by the notation dV/dt . The steeper the edges that define the voltage pulses of the voltage waveform, the higher the value of dV/dt .

The nature of the phase windings in most electric motors causes the motor to appear as a highly inductive load at the end of the connection cables 14, 16 and 18 coupling the motor 10 to the controller 12. At the high switching frequencies and high dV/dt of modern controllers, the inductive load of the motor appears, at least transiently, as an open circuit. Accordingly, the application of high frequency voltage pulses with steep edges (i.e., a high dV/dt) to the motor can result in extreme voltage transients at the points where the connection cables 14, 16 and 18 are coupled to the phase windings of the motor 10. In some systems, the magnitude of these transient voltages can rise to nearly twice the magnitude of the applied voltage pulses.

In new motors, the insulating coating of enamel covering the wire comprising the phase windings is generally sufficient to handle the voltage spikes caused by the application of the high frequency, high dV/dt voltage pulses. Over time, however, the insulating properties of the enamel coating degrade and a point may be reached where it is no longer capable of handling the voltage spikes resulting from the high frequency pulses. In such instances, the failure of the insulating coating can result in a shorting of winding turns when the voltage stresses caused by the high frequency pulses are applied to the

phase windings. Experience has shown that this shorting of winding turns occurs most often in the turns physically adjacent the point where the connection cable is connected to the phase windings. These shorted turns can create a closed circuit where circulating currents are produced. These circulating currents give off heat that tends to further degrade the insulating properties of the wire comprising shorted turns and the winding turns physically adjacent the shorted turns. This heat, in turn, results in additional insulation failures, which result in additional shorted turns. A vicious cycle is instigated which usually results in extreme damage to the motor winding and failure of the motor itself.

The problem of voltage stress induced winding failures in motors has been recognized within the motor art and has been addressed, for example, in D. Potoradi et al., "Transient Overvoltages Caused by Switching of High Voltage Asynchronous Machines and their Distribution in Stator Windings," 2 Proceedings of the International Conference of Electrical Machines 644-49 (September 5-8, 1994) and K.J. Cornick et al., "Steep-fronted Switched Voltage Transients and their Distribution in Motor Windings" 136 IEE Proceedings 45-55 (March 1982).

The problem of voltage stress induced winding failure can occur in any motor system in which high frequency voltage pulses or voltage pulses having a high dV/dt are applied to a motor. In particular, this problem can appear in AC induction motor systems, permanent magnet motor systems, and reluctance motor systems. To date, efforts to resolve this problem have not been adequately successful.

This invention provides a solution to the winding failure problem particularly applicable to reluctance motor systems, although not necessarily limited thereto.

The present invention is defined in the accompanying independent claims. Preferred features are recited in the claims respectively dependent thereon.

In one embodiment of the present invention, a method and apparatus are provided for reducing the risk of winding failures in switched reluctance machines by reducing the turn-to-stator capacitance of the winding turns of the phase windings connected to an external controller via the machine terminals. This reduction in the turn-to-stator capacitance of the phase windings distributes voltage stresses more evenly throughout the phase winding, resulting in a reduced risk of winding failures.

In another embodiment of the present invention, additional insulation in the form of wrapped sheets or insulating sleeves is provided for the outermost winding turns of the phase windings of a switched reluctance machine, where these turns are at an end of the winding to which a connecting cable is attached. In this embodiment, the additional insulation enables the outermost winding turns to better handle the voltage stresses resulting from the high frequency voltage pulses associated with the machine windings. In still another embodiment,

iment of the present invention, a sheet of insulating material is positioned between the outermost layer of winding turns and the next inwardly adjacent layer.

In yet another embodiment of the present invention, a capacitive voltage distributor is positioned between the outermost layer of winding turns and the next inwardly adjacent layer of winding turns in a switched reluctance machine. This capacitive voltage distributor distributes more evenly the voltage stresses resulting from the application of voltage pulses to the motor throughout the motor winding, thereby reducing the risk of winding failures caused by concentrated voltage stresses.

The present invention can be put into practice in various ways some of which will be described by way of example with reference to the accompanying drawings in which:

Figure 1 illustrates an exemplary adjustable speed machine system which may be used in connection with the methods and apparatus of the present invention;

Figure 2 illustrates a typical reluctance machine;

Figure 3A generally illustrates in cross section a portion of a phase winding associated with one pole of a switched reluctance motor;

Figure 3B generally illustrates the winding configuration often found in machines other than switched reluctance motors, such as induction machines and most permanent magnet machines;

Figure 4A provides a simplified schematic representation of the first portion of a phase winding of a typical electric machine;

Figure 4B illustrates a further simplified schematic representation of the first portion of a phase winding of a typical electric machine;

Figure 5 generally illustrates a coil for a phase winding for a reluctance machine formed and positioned in accordance with the present invention;

Figure 6 illustrates an embodiment of the present invention in which air-gaps are introduced into the phase winding to decrease the turn-to-stator capacitance of the outermost winding turns;

Figure 7 illustrates an alternate embodiment of the present invention in which additional insulation is provided for the outermost winding turns of a reluctance machine to enable them to better handle the voltage stresses caused by the high frequency voltage pulses;

Figure 8 generally illustrates another embodiment of the present invention in which an insulating sheet is provided between the outermost layer and the immediately inwardly adjacent layer;

Figure 9 illustrates yet another embodiment of the present invention in which a conductive layer is used to distribute the voltage spikes that result from the application of high-frequency voltage pulses to the machine; and

Figure 10 illustrates a modification of the embodiment illustrated in Figure 9 in which a capacitive voltage distributor comprises a helically wound strip.

Similar reference characters indicate similar parts throughout the several views of the drawings.

Figure 2 illustrates a typical reluctance machine having a rotor 28, including four rotor poles 29 and a stator 20 including six stator poles 21-26. Associated with each stator pole is a wound coil of wire 27. In the illustrated machine, the coils of opposing stator poles are coupled together to form three phases: phase A (coils from poles 21 and 24); phase B (coils from poles 22 and 25); and phase C (coils from poles 23 and 26). In the example illustrated in Figure 2, when phase A is energized, electric current will flow through its coils such that stator pole 21 becomes, in one example, an inward-pointing electro-magnet of positive polarity and stator pole 24 becomes an electro-magnet of negative polarity. When the machine is operating as a motor, these combined electromagnets cause a force to be exerted on the rotor 28 tending to cause it to rotate in a counter-clockwise direction. Through sequential energization of the phase windings, rotation of rotor 28 can be initiated and maintained resulting in the production of torque along a shaft (not shown) coupled to the rotor.

For the sake of convenience the following description refers to reluctance motors. The skilled person will be aware that the construction of a switched reluctance generator is the same as that of a switched reluctance motor. Thus, the invention is applicable to both generators and motors to substantially equal effect. Although the following discussion focuses on switched reluctance motors, the present invention is applicable to all forms of reluctance machines, and other machines having phase winding arrangements similar to those of switched reluctance machines.

Unlike many electric motors, such as induction motors and most permanent magnet motors, the phase windings of switched reluctance motors are not contained in stator slots. This difference between switched reluctance motors and more common electric motors is illustrated in Figures 3A and 3B.

Figure 3A generally illustrates in cross section the portion of a phase winding associated with one pole of a switched reluctance motor. The portion of the winding associated with the opposing pole is substantially identical. The turns encircle the opposing pole in the same direction such that electromagnets of opposing polarities are created when the phase winding is energized.

Referring to Figure 3A, several turns of enamel coated wire (typically copper) are wrapped around a stator pole 21 of a switched reluctance motor. These turns make up a unit that is referred to as a winding coil. The turns are typically wound from the inside out such that the first turn is at the position indicated by turn 30. The next turn is positioned at the adjacent position indicated

by turn 32, with the further turns being wound in adjacent positions until the last turn for the layer (position 34) is wound. The winding then proceeds to another layer, this one being wound from the outside (position 35) inwards to the base of the stator pole. The turns are then wound in the same fashion until the desired number of turns are obtained. Typically extra lengths of wire extend from the first turn 30 to form a first end adapted for connection to a motor terminal and thence to an external electronic motor controller via a connection cable. Similarly, extra lengths extend from the last turn 36 to form a second end adapted for connection to another winding coil of the phase winding.

Figure 3B generally illustrates the winding configuration found in many other types of electrical machines, such as induction motors and most permanent magnet motors. In such motors, the wire turns that comprise the phase windings are placed in semi-closed slots 38 formed by inwardly protruding teeth 39.

Unlike the more typical electric motor winding arrangement illustrated in Figure 3B, the switched reluctance motor does not utilize semi-closed slots. The inventor of the present invention has recognized that the different nature of switched reluctance motors allows for the implementation of novel techniques for reducing voltage stress induced winding failures.

Figure 4A provides a simplified schematic representation of the first portion of a phase winding in an electric motor, such as a switched reluctance or an induction motor. Generally, the phase winding appears as a number of series connected inductors 40, 42, 44 and 46. Each of these inductors represents a number of winding turns. Associated with each of these inductors are a number of capacitive elements. These capacitive elements represent the capacitances resulting from the nature of motor windings. Capacitors C_{TG} represent the turn-to-ground capacitance resulting from the winding turns' interaction with the stator material around which the winding coils are placed. This stator material is usually coupled to ground. For motors where the stator material is not coupled to ground, the turn-to-ground capacitance C_{TG} is the turn-to-stator material capacitance. Capacitor C_{T40-42} represents the inherent capacitance between neighbouring groups of winding turns. Although not illustrated, similar capacitances would be associated with the winding turns represented by inductors 42 and 44, also 44 and 46. Capacitors C_{T40} and C_{T42} represent the turn-to-turn capacitance resulting from the winding turns interaction with each other. Similar capacitances would be associated with the winding turns represented by inductors 44 and 46. As those skilled in the art will recognize, Figure 4A illustrates only a portion of the winding with its associated capacitances appearing in a motor winding arrangement. The inventor of the present invention has recognized that the combined effect of these capacitances ensures that the worst voltage stresses caused by the high frequency voltage pulses (or waveforms having high dV/dt) occur in the turns

of the winding nearest to the associated connection cable.

Figure 4B illustrates a further simplified representation of the first portion of a phase winding of an electric motor. The inductances and capacitances of the winding turns other than turns nearest to the associated connection cable have been combined for purposes of illustration and are represented by an inductor 47 and a capacitor 48. As in Figure 4A, the inductor 40 represents the winding turns nearest to the connection cable and capacitor C_{TG} represents the turn-to-ground capacitance of these turns.

Because of the nature of inductive and capacitive circuits, the magnitude of the voltage stresses placed on the inductor 40 when a high dV/dt voltage pulse is applied to the winding will vary with the capacitance of the capacitor C_{TG} . As the capacitance of the capacitor C_{TG} increases, the voltage stresses placed on the inductor 40 increase. As the capacitance of the capacitor C_{TG} decreases, so does the voltage stress placed on the inductor 40. This reduction in voltage stress occurs because, as C_{TG} is lowered, the voltage stresses are distributed more evenly between the inductors 40 and 47.

From the above analysis of the simplified circuit of Figure 4B it may be deduced that a reduction in the turn-to-ground capacitance of turns of a motor phase near to the controller and its connection cables will result in a reduction of voltage stresses placed on that portion of the motor winding, and a corresponding reduction in the likelihood of a voltage stress induced failure of the winding. The inventor has developed a novel approach for reducing the turn-to-ground capacitance of the turns of a switched reluctance motor that are coupled to the external controller.

Referring to Figure 3A, it may be noted that the turn-to-ground capacitance of a winding turn is strongly tied to the relative position of the winding turn with respect to the stator pole 21 in the inter-pole portion 33 of the stator. For example, the winding turn 30 is located physically near pole 21 in the inter-pole region 33, and will have a relatively high turn-to-ground capacitance. Winding turn 31, being located more distant from the stator pole 21, has a lower turn-to-ground capacitance than the turn 30. Winding turn 37 has a still lower turn-to-ground capacitance.

According to the present invention, the winding turn having an end coupled to the connection cable for a given phase should be located at the position where the turn-to-ground capacitance is minimized. This is illustrated generally in Figure 5. Referring to Figure 5, the winding turn having the lowest turn-to-ground capacitance is the turn 50 located at the position most distant from the pole 21 (distance A) and the inter-pole region 33 (distance B). In the present invention, the wire portion extending from winding turn 50 should be coupled to the motor terminal and hence to the connection cable. Such a winding arrangement minimizes the voltage stresses

on the turn 50 by reducing its turn-to-ground capacitance, resulting in a better distribution of the voltage stresses caused by the high frequency or high dV/dt voltage pulses. This distribution in voltage stresses can result in a reduction in the number of motor windings that suffer voltage stress induced winding failure.

Figure 6 illustrates another aspect of the present invention. As those skilled in the art will recognize, it often occurs that the number of turns associated with a pole in a switched reluctance motor will not always result in the last wound turn being the last turn in a complete layer of turns, as is illustrated in Figure 5. Typically, the last wound turn is positioned somewhere other than the last turn of a full layer. This is illustrated in Figure 3A where the last wound turn 36 is the third turn of the final layer in a winding arrangement having ten turns per full layer.

In accordance with the present invention, the outermost layer of turns, if partial, may be positioned, depending on the number of layers, such that the last turn is at a position further away from the stator pole 21 (distance A) and the inter-pole region 33 (distance B) than shown in Figure 3A. This is illustrated in Figure 6, where the outermost layer 52 is partial and positioned such that the last wound turn 54 is located in the position most distant from the pole 21 and inter-pole region 33. As Figure 6 indicates, this winding arrangement results in air-gaps 56. Thermally conductive (but electrically insulating) elements could be placed in air-gaps 56 to improve the thermal conductivity of the system. In manufacture, dummy spacers may be used to produce the air-gaps 56.

As those skilled in the art will appreciate some winding connections for switched reluctance machines are such that, say, four coils are connected in series to form the phase winding. In such cases, only the outermost ends of the phase windings need to be arranged as shown in Figures 5 or 6.

It should be noted that the particular approach for reducing voltage stress induced winding failures is particularly suitable for switched reluctance motors. The same approach cannot be used with some varieties of electric motors, such as induction and permanent magnet motors. Referring back to Figure 3B it may be noted that where the windings are placed in slots, there is no single outer turn that has a relatively low turn-to-ground capacitance. Accordingly, there is no turn particularly suitable for coupling to the connection cable and motor terminal so as to reduce voltage stresses in the winding. While the centrally positioned winding turns would have a relatively low turn-to-ground capacitance compared to the outer turns, it is difficult in practice to couple the connecting cable to such centrally positioned turns. It should be apparent, therefore, that the winding arrangements of the present invention are particularly suited for switched reluctance motors since in switched reluctance motors there is a turn particularly suitable for coupling to a connection cable.

Alternative embodiments for reducing voltage

stress induced failures in switched reluctance motors are contemplated. In one such embodiment, additional insulation is provided for the outermost turns to enable them to better handle the voltage stresses caused by the high frequency or high dV/dt voltage pulses. Figure 7 generally illustrates this embodiment.

As illustrated in Figure 7, additional insulating material 72 is provided around the last few turns of the winding. This insulating material 72 can be wrapped around the last few winding turns 70, or an insulating sleeve can be provided for the wire portions that comprise the last few turns. Potential wrapping materials include polyamide film such as KAPTON (a trademark of DuPont) and the like, and potential insulating sleeves include acrylic sleeveings, glass sleeveings, sleeveings formed from glass braid, and similar materials. Although the alternative winding arrangement discussed above (i.e., that with the introduced air-gap 56 in Figure 6) is not illustrated in Figure 7, the use of insulation is compatible with that winding arrangement also.

Further embodiments are contemplated where an insulating sheet is provided between the outermost layer and the immediately inwardly adjacent layer. This embodiment is illustrated in Figure 8, where a sheet of insulating material 73 is arranged between the outermost layer 74 and the immediately adjacent inner layer. It is not essential that the sheet of insulating material 73 extend across the entire span of the outermost layer 74, as long as it extends under the last few turns of the winding. The particular composition of the insulating sheet is not essential to the present invention, but should be selected to be a relatively thin material with high dielectric strength and good thermal conductivity. A calendared aramid paper such as NOMEX (a trademark of DuPont) is believed to be a suitable material.

Yet another embodiment is contemplated for reducing winding failures in switched reluctance motors. In this embodiment a conductive layer is used to distribute capacitively the transient voltage spikes that occur over the last few winding turns to other winding turns. As with the first embodiment discussed above, this results in a distribution of the voltage stresses among a greater number of winding turns, and reduces the risk of voltage stress induced winding failure. This embodiment is generally illustrated in Figure 9.

In this embodiment, a layer of conductive material 76 is sandwiched between two layers of insulating material 78a and 78b. The sandwich of conductive material is then placed between the outermost layer 74 and the next inwardly adjacent layer. A wire or other electrically conductive member 80 connects the last winding turn to the conductive layer 76. The dimensions of the conductive layer 80 are not critical as long as its free ends do not make electrical contact with any other component connected to ground potential. The conductive material 76 may comprise aluminum, copper, conductive plastic, a graphite conductive mat or the like. Embodiments are also contemplated where the sandwich of conductive

material is formed by two sheets of metallised plastic, such as metallised KAPTON or metallised NOMEX, or one metallised sheet and one unmetallised sheet.

In the embodiment illustrated in Figure 9, the conductive sandwich forms a capacitive voltage distributor that distributes the voltage stresses that are placed on the last few winding turns when a high frequency or high dV/dt voltage pulse is applied to the motor. As a review of Figure 9 illustrates, the combination of the outer layer of winding turns 74, the insulating layer 78a and the conductive layer 76 forms a capacitive element. Accordingly, as the voltage on the outer layer of winding turns begins to rise in response to an applied voltage pulse, the voltage potential of the conductive layer 76 will also begin to rise. Because of capacitive coupling between the capacitive layer 76 and winding turns other than the outermost turns (including the turns comprising the next-to-outermost layer of the winding) the voltage stresses that would otherwise be concentrated in the outermost turns are distributed and shared by other turns in the coil. This distribution of voltage stresses can reduce the likelihood of voltage stress induced winding failure.

As described above, the conductive element 76 serves as a capacitive voltage distributor even if it is not electrically connected to the outermost turns. However, when the conductive element 76 is electrically coupled to the outermost turns, the distribution of the voltage stresses throughout the motor windings will be improved. Accordingly, in embodiments where it is practicable, it may be desirable to use a conductive member 80 to electrically couple the last turn 74 in the coil with conductive element 76.

Alternative embodiments are contemplated in which the capacitive voltage distributor formed by the conductive element 76 comprises a helically wound strip rather than a sheet of conductive material sandwiched between insulators. A cross-sectional view of one such embodiment is illustrated in Figure 10 where a helically wound strip 82, is positioned between the outermost 88 and next adjacent 90 layers of the winding.

It should be noted that the particular winding arrangement used in switched reluctance motors makes the insertion of insulating sheets or conductive sandwiches relatively easy when compared with the practical difficulties that would be encountered if such approaches were attempted on more common motors where the windings are placed in narrow slots.

While the invention has been described in connection with the illustrative embodiments discussed above, those skilled in the art will recognize that many variations may be made without departing from the present invention. For example, the present invention is applicable to machines with different number of rotor and stator phases than illustrated herein and with different number of coils per phase. Moreover, the present invention is also applicable to machines with series, series and parallel or parallel connections of coils within a phase. Further, the invention is applicable to inverted

machines in which the stator is in the center of the machine and the rotor rotates around the outside of the stator. Also, a machine such as a reluctance or induction machine can be constructed as a linear motor in which the moving member is often referred to as a rotor. The term 'rotor' herein is intended to embrace such moving members of linear motors. Accordingly, the above description of several embodiments is made by way of example and not for purposes of limitation. The present invention is intended to be limited only by the spirit and scope of the following claims.

Claims

1. A method of assembling a switched reluctance drive including a reluctance machine, having a stator defining stator poles and inter-pole regions, at least one electrically conductive winding and a controller for controlling energisation of the winding, the controller having first and second terminals for the supply and return of current, respectively, the method comprising arranging the winding around one of the stator poles, the winding having first and second ends, the first end being arranged in relation to the surface of the stator pole and/or the inter-pole region to have a first turn-to-stator capacitance, and the second end being arranged in relation to the surface of the stator pole to have a second, higher, turn-to-stator capacitance; and connecting the first end of the winding to the first terminal of the controller.
2. A method as claimed in claim 1, including a plurality of the stator poles each having its own winding.
3. A method as claimed in claim 2, wherein at least some of the windings arranged around the plurality of stator poles are connected in series the said first end of one of the windings being connected with the first terminal of the controller and the second end of another one of the windings being connected with the second terminal of the controller.
4. A method as claimed in claim 1, 2 or 3, wherein the winding comprises a plurality of layers of winding turns including an outermost layer, the method further comprising the step of forming the winding so that the first end extends from the outermost layer.
5. A method as claimed in claim 4, wherein the outermost layer of the winding turns is spaced from the inter-pole region of the stator.
6. A method as claimed in claim 5, further comprising the step of arranging a thermally conductive, electrically insulating sleeve around at least one of the winding turns.

7. A switched reluctance drive comprising a reluctance machine, including a stator having stator poles defining inter-pole regions and a winding arranged around at least one of the stator poles, the winding having first and second ends, the drive further comprising a controller operable to control energisation of the winding, the controller having first and second terminals for the supply and return of current to and from the winding, respectively, the first end of the winding being arranged in relation to the surface of the stator pole and/or the inter-pole region to have a first turn-to-stator capacitance, and the second end being arranged in relation to the surface of the stator pole to have a second, higher, turn-to-stator capacitance, the first end of the winding being connected with the first terminal of the controller.
 8. A drive as claimed in claim 7, wherein the second end is connected to another winding.
 9. A drive as claimed in claim 7 or 8, wherein the winding comprises a plurality of layers of winding turns including an outermost layer, the first end extending from the outermost layer.
 10. A drive as claimed in claim 9, wherein the winding defines a space between the inter-pole region of the stator and the outermost layer of winding turns.
 11. A drive as claimed in any of claims 7 to 10, including a plurality of windings, wherein at least some of the windings are connected in series, the first end of one of the windings being connected with the first terminal of the controller and the second end of another of the windings being connected with the second terminal of the controller.
 12. A drive as claimed in any of claims 7 to 11, including electrically insulating material positioned between at least one of the winding turns next to the first end and the winding turns of an adjacent layer.
 13. A drive as claimed in claim 12, wherein the insulating material comprises a insulating sheet wrapped around at least one of the winding turns.
 14. A drive as claimed in claim 13, wherein the insulating sheet extends between the outermost layer and the adjacent layer of the winding turns.
 15. A drive as claimed in claim 12, wherein the insulating material comprises insulating sleeving surrounding at least one of the winding turns.
 16. A drive as claimed in claim 7, in which the winding comprises a number of layers of winding turns and includes an outermost layer of winding turns, the stator of the drive further comprising a capacitive voltage distributor positioned between at least a portion of the outermost layer of winding turns and at least a portion of the immediately adjacent layer of the same winding, the capacitive voltage distributor comprising a conductive element arranged between two insulating layers.
 17. A drive as claimed in claim 16, wherein the conductive element is electrically connected to the winding.
 18. A drive as claimed in claim 17, wherein the conductive element is electrically connected to the first end of the winding.
 19. A drive as claimed in claim 16, wherein the capacitive voltage distributor is arranged across the extent of the outermost layer of winding turns.
 20. A drive as claimed in claim 16, wherein the capacitive voltage distributor comprises a helically wound strip.

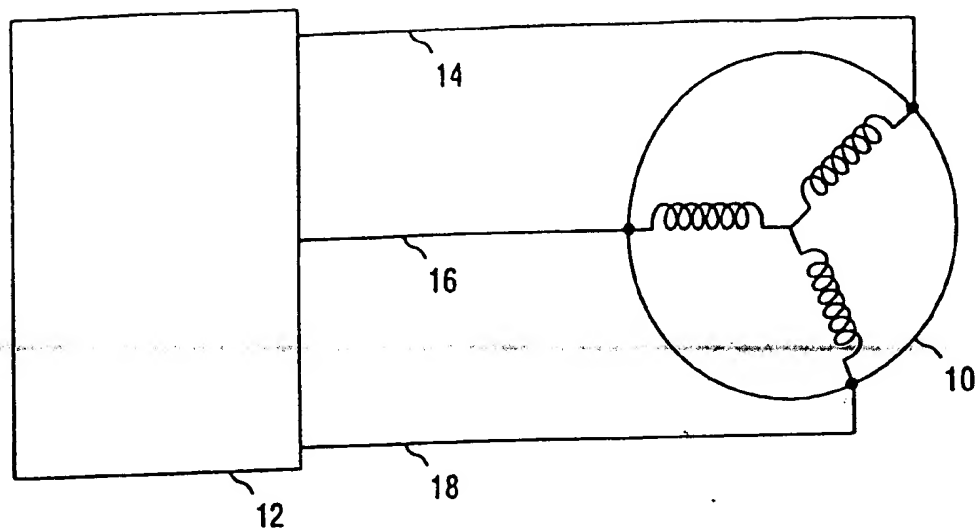


Fig 1

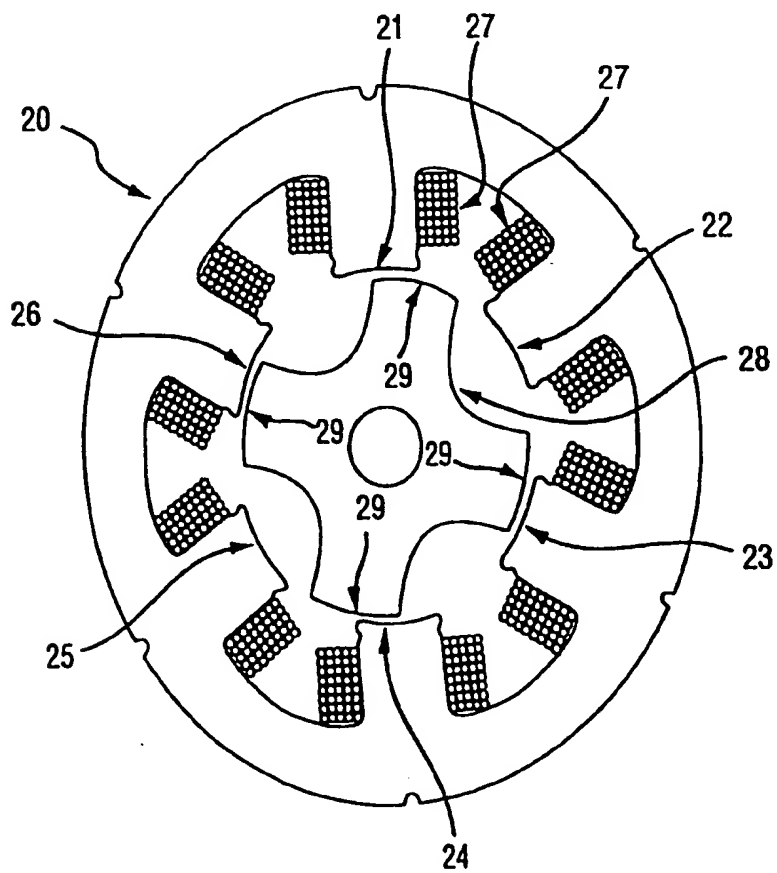


Fig 2

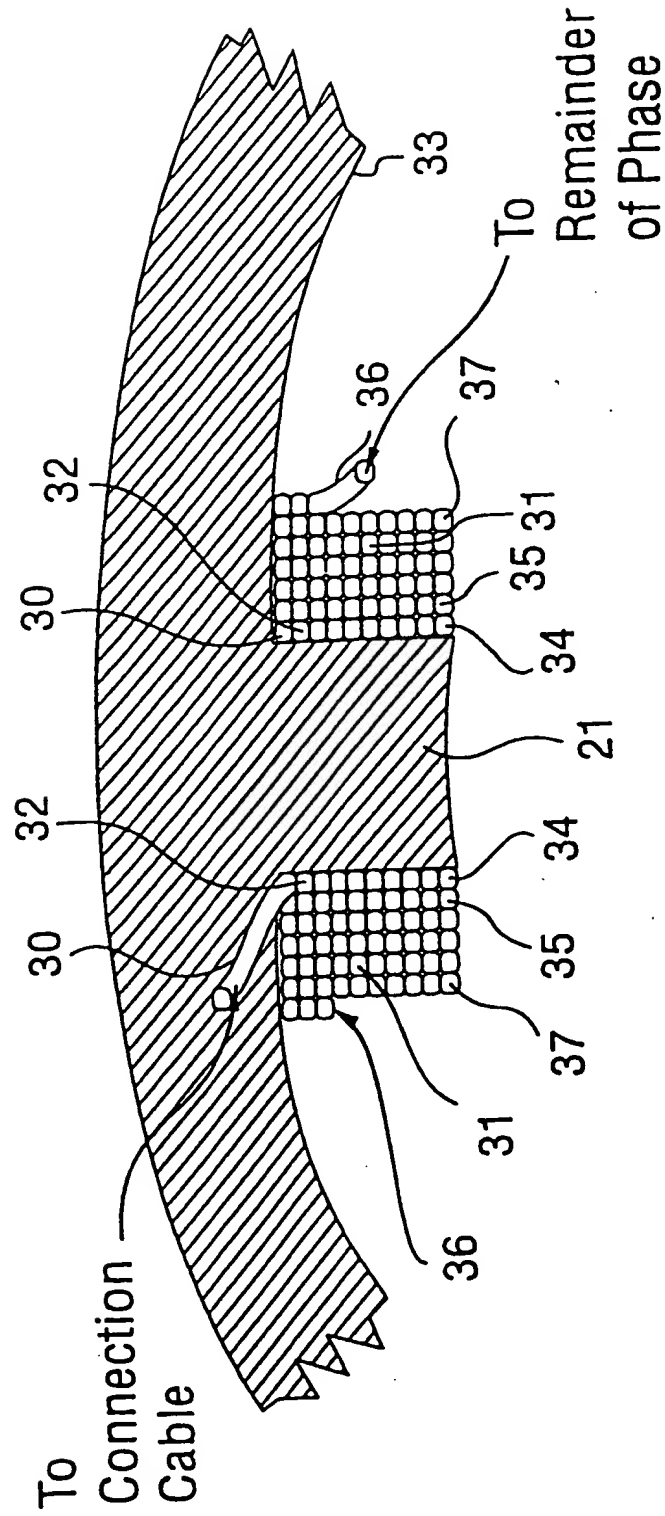


Fig 3A

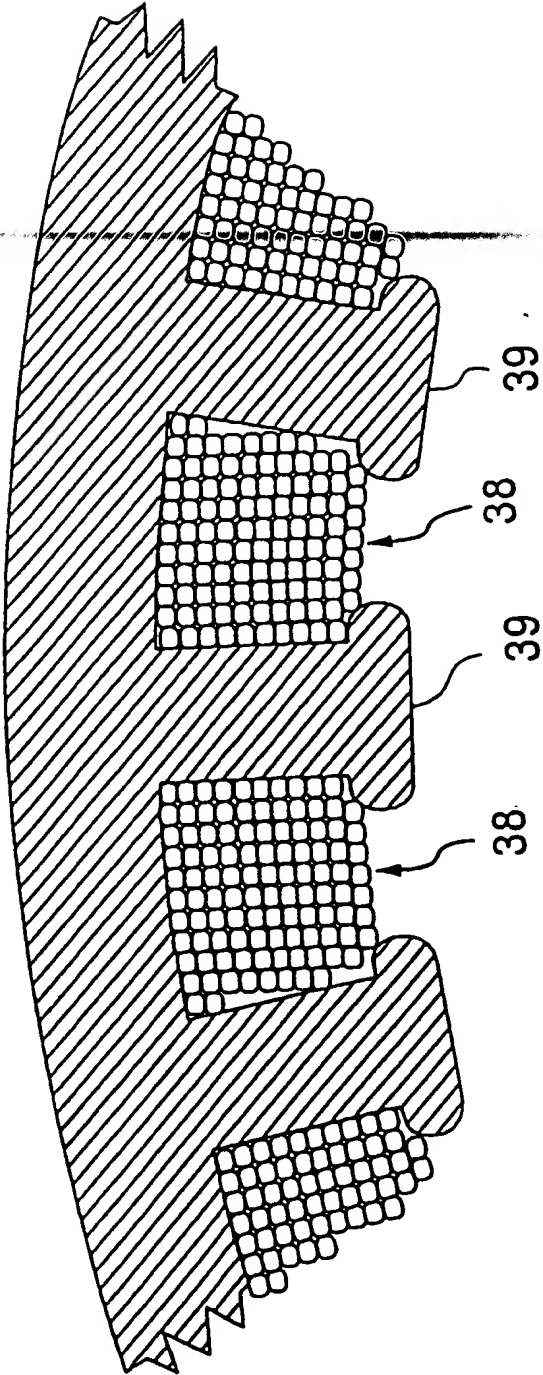


Fig 3B

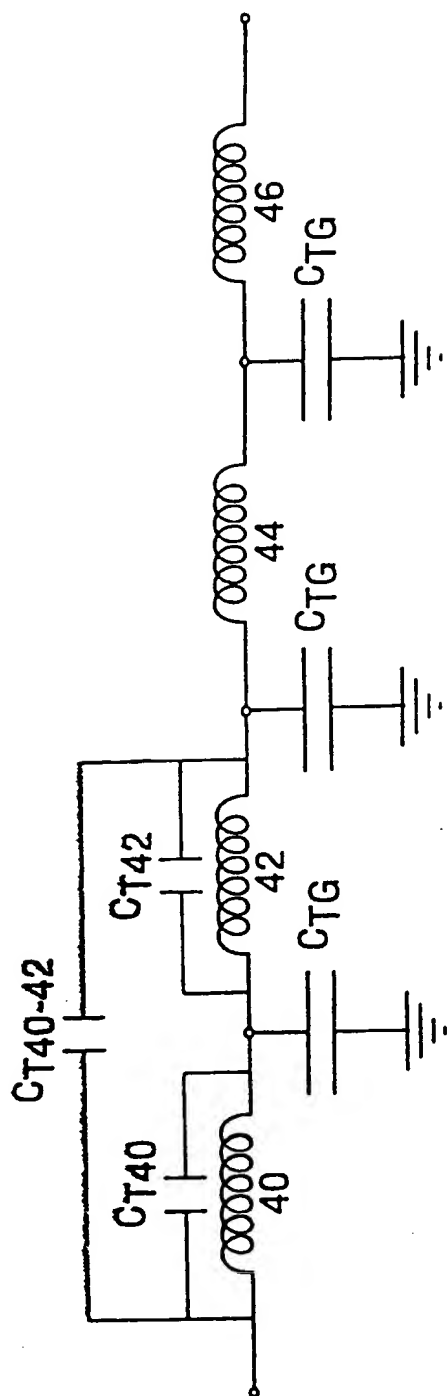


Fig 4A

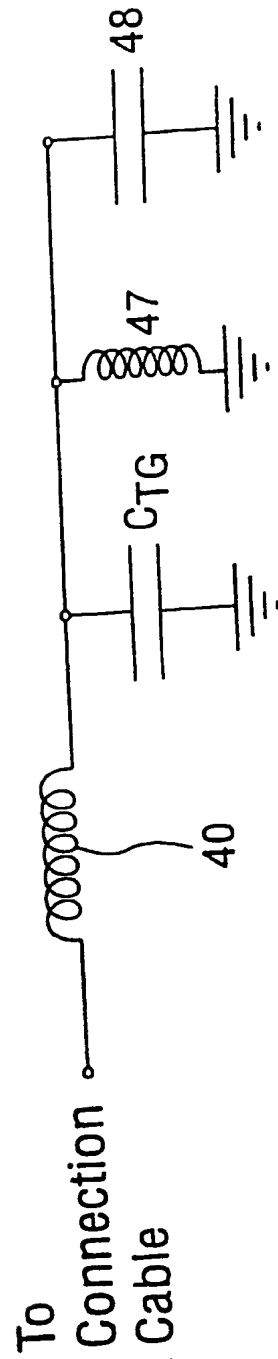


Fig 4B

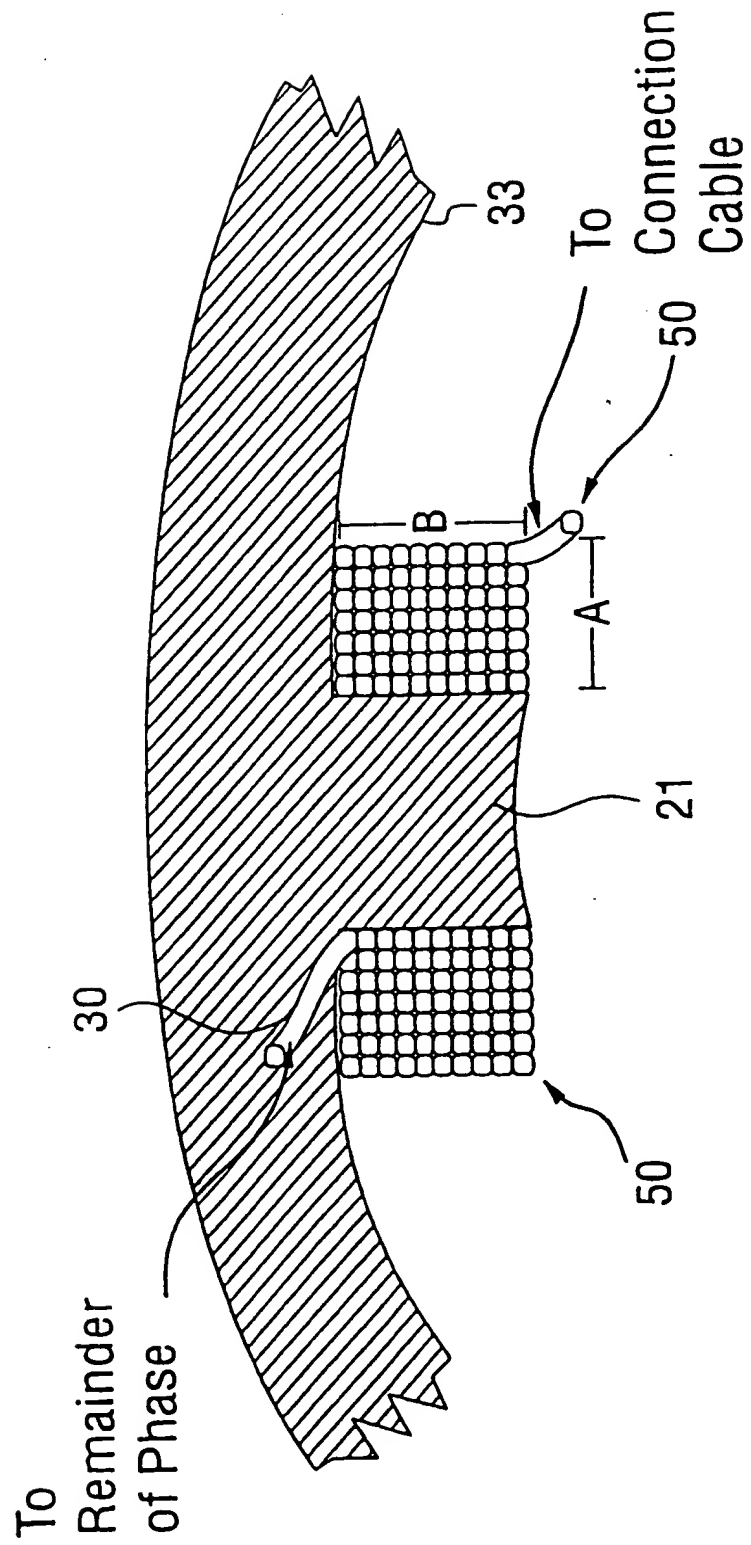


Fig 5

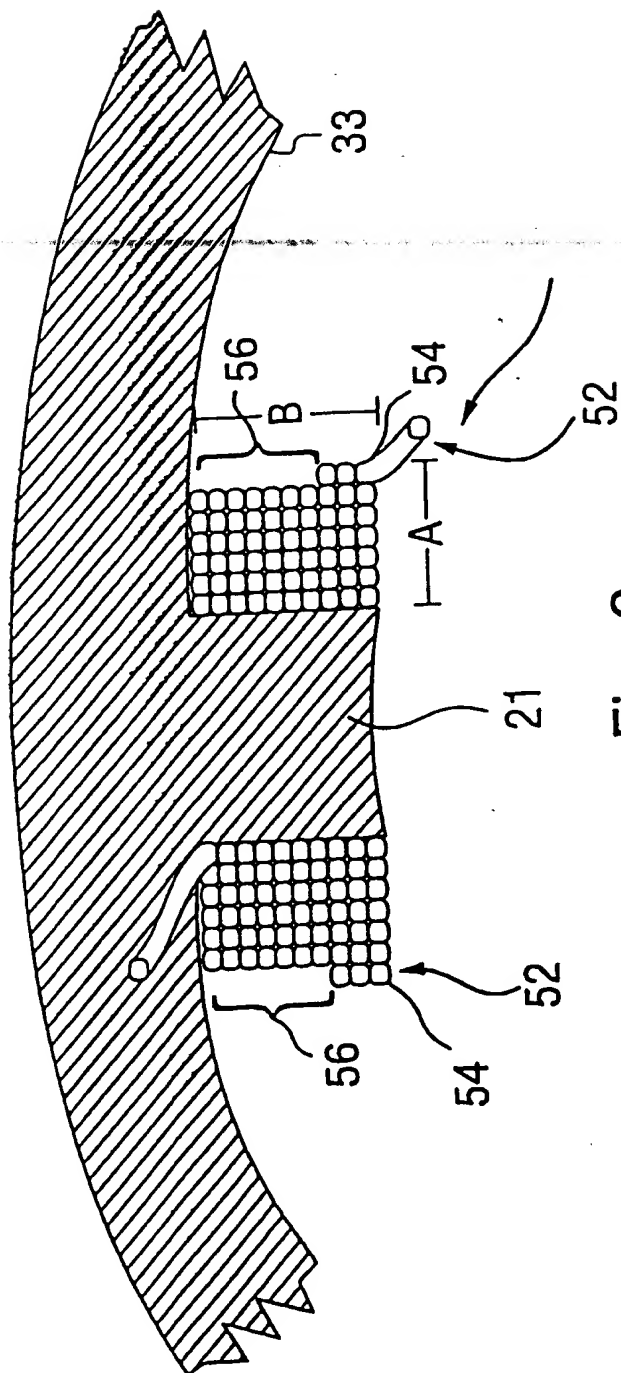
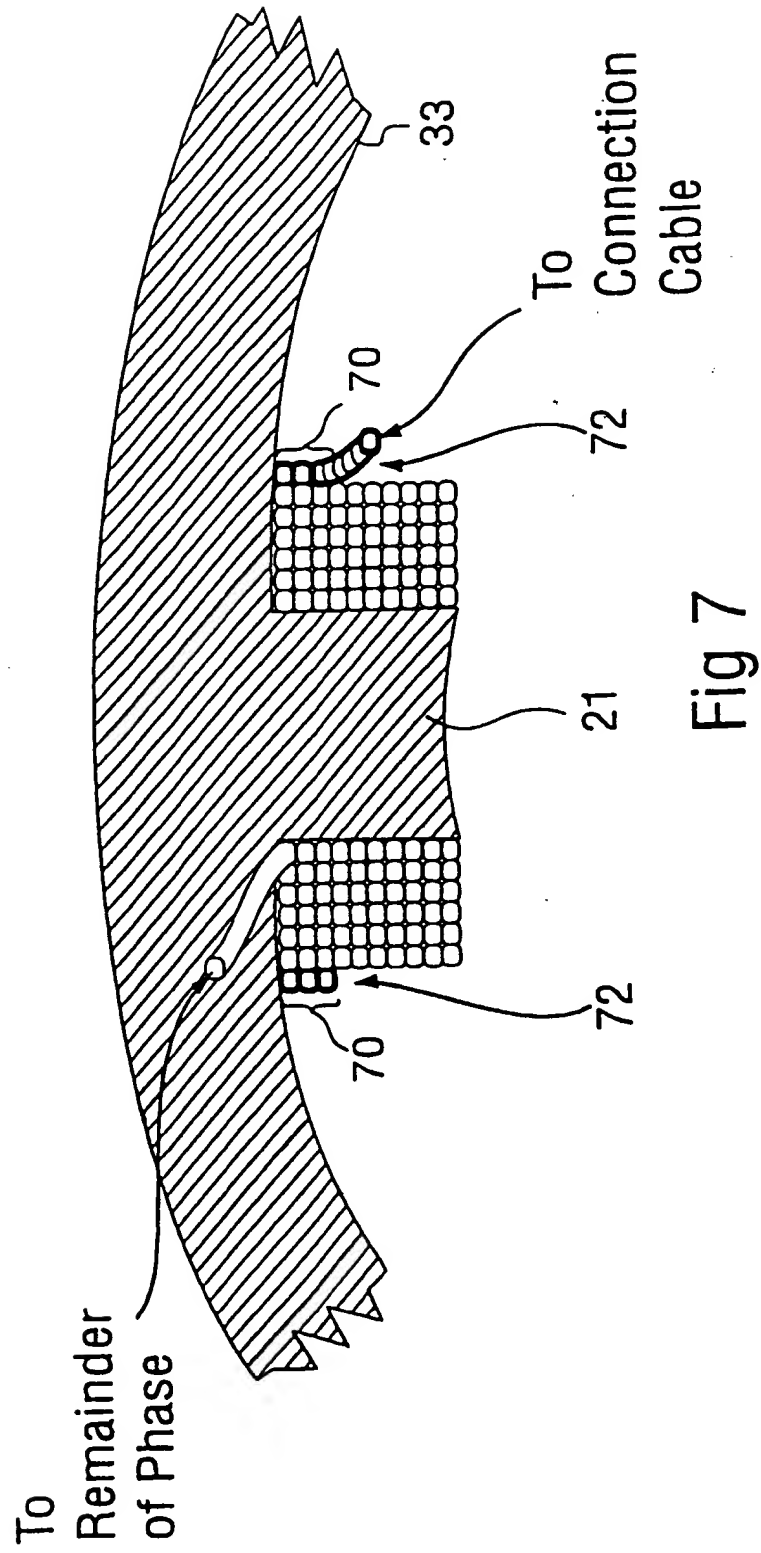


Fig 6



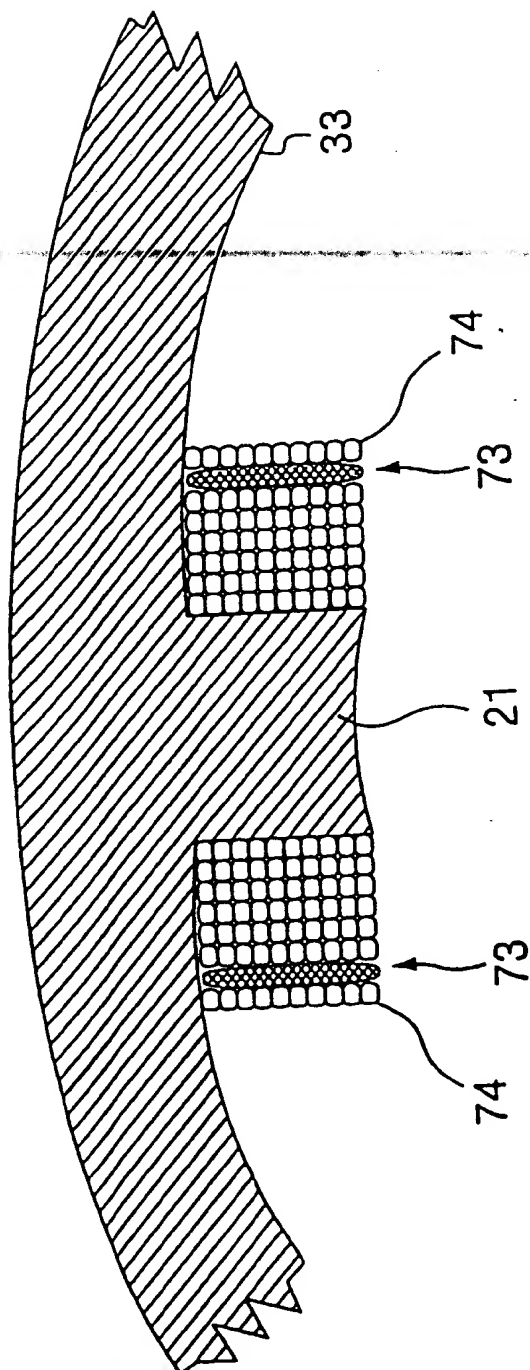


Fig 8

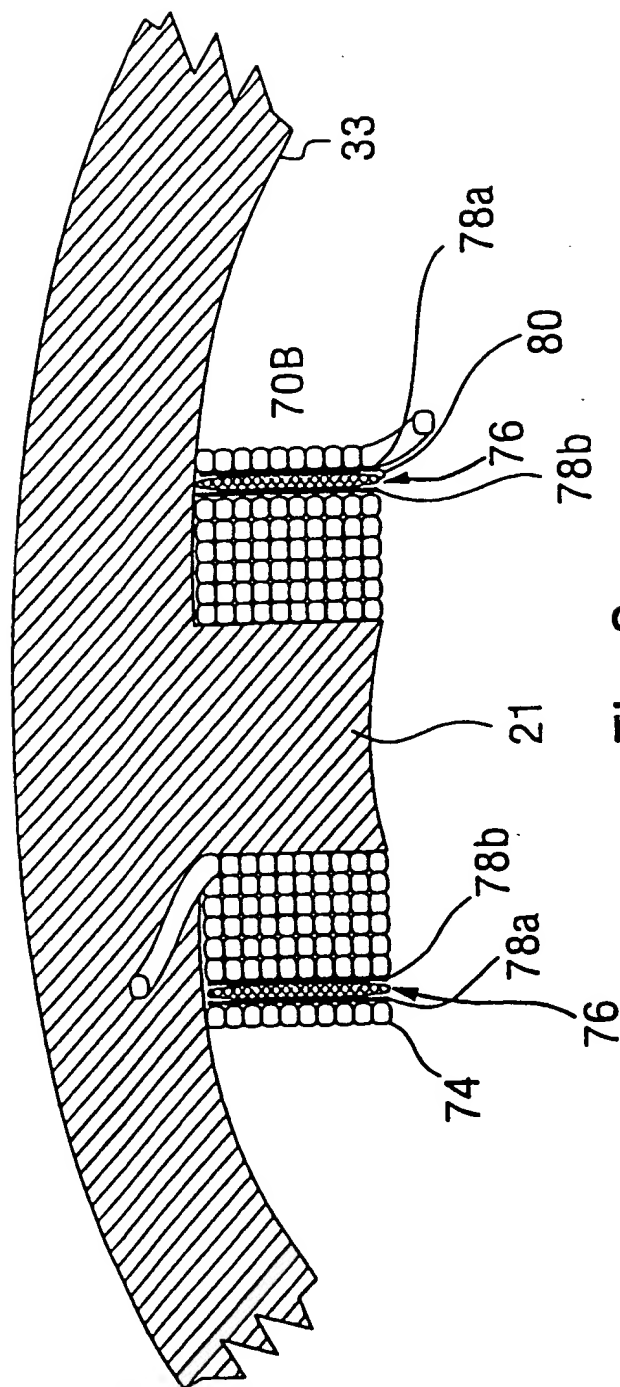


Fig 9

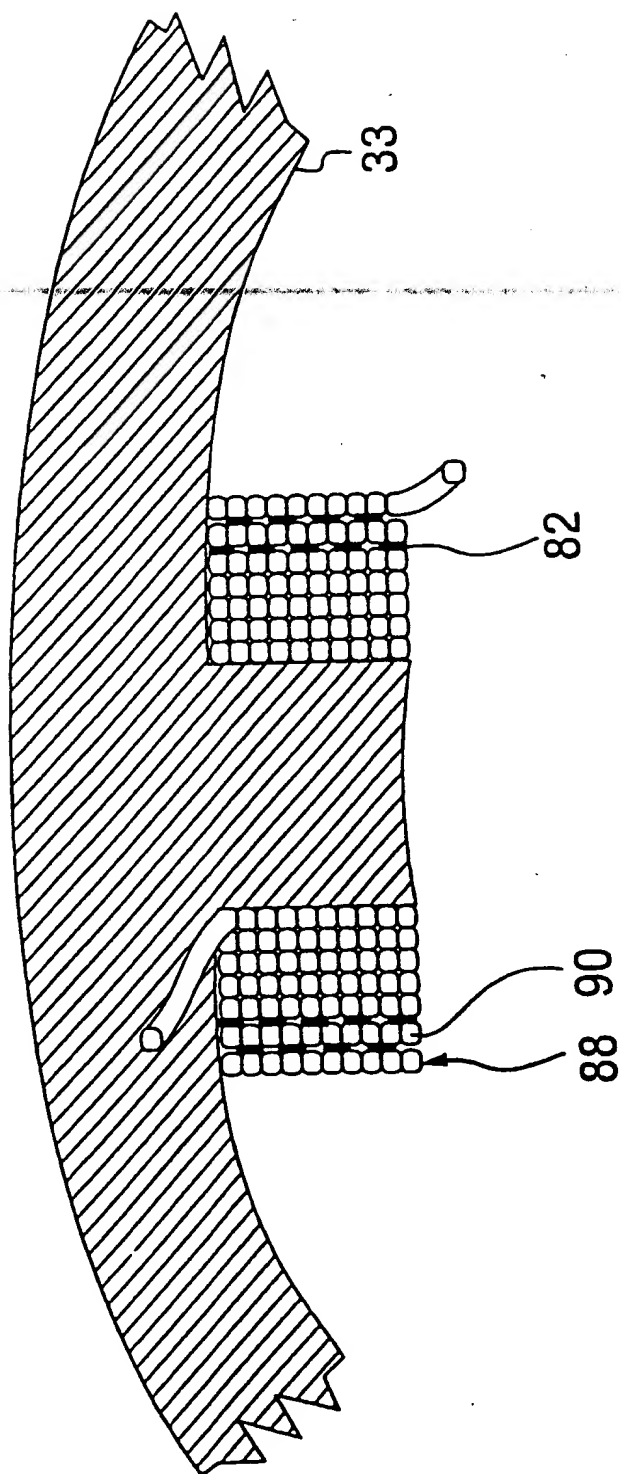


Fig 10